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THE ECOLOGY OF THREE SMALL LAKES NEAR KAIKOURA, NEW ZEALAND

V.M. STOUT

Department of Zoology, University of Canterbury,
Christchurch, New Zealand

ABSTRACT

The origin, physical and chemical characteristics, and biology of Lakes Rotorua, Rotoiti and Leg of Mutton, near Kaikoura, are described. These are small, shallow, eutrophic lakes, usually very turbid with silt or algal blooms. There are few molluscs, and the invertebrates are mostly crustaceans or insects. *Boeckella hamata* (Copepoda, Calanoida) is dominant in the zooplankton. The lakes support an abundant and diverse bird fauna, which contribute to the nutrient content, especially the shags (Family Phalacrocoracidae) which roost in dead willow trees around Lake Rotorua. Leaves from the willows surrounding Leg of Mutton lake make a significant contribution to the organic matter in the lake.

KEYWORDS: lakes, Kaikoura, turbid, guanotrophic, limnology, *Boeckella hamata*.

INTRODUCTION

Lakes Rotorua, Rotoiti and Leg of Mutton are in undulating hill country about 7-8 km west of Kaikoura, between the Kowhai and Kahutara Rivers (Figure 1). Lake Rotorua, the largest, lies along a north-south axis, close to the Kahutara River. Lake Rotoiti and the smallest lake, Leg of Mutton, are further to the east, with Leg of Mutton closest to the sea. The lakes are probably best known for their bird fauna. They support a diversity of waterbirds, including shags which roost along the edges of Lake Rotorua in particular. Duck shooting is popular in season, especially on Leg of Mutton lake.

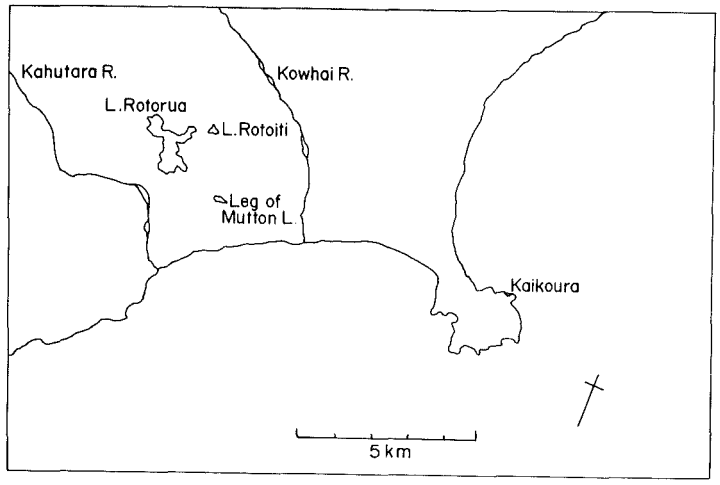

Figure 1. Location of the lakes.

ORIGIN

All three lakes are of recent origin, formed from previous tributaries of the Kahutara and Kowhai Rivers. The greywacke shingle in these broad aggrading river beds has been deposited at the mouths of the former tributaries, damming them to form Lake Rotorua from the Kahutara River, and Lakes Rotoiti and Leg of Mutton from the Kowhai River (Chandra, 1969).

CATCHMENT

The surrounding soils are yellow-brown earths, overlain at lower altitudes by alluvium brought down by the rivers. The soils are mostly heavy, slow draining, and of moderate to low fertility, supporting brown-top pastures and manuka scrub. In a few areas the soil has responded to oversowing and top-dressing with phosphate to yield good pasture (Gibbs and Beggs, 1953).

The catchments of the lakes are hilly farming country, supporting mostly sheep and cattle, which have access to the lakes. The vegetation covering the hills was probably once a Podocarp-mixed Hardwood forest, but now manuka (*Leptospermum* sp.) and wild briar (*Rubus* sp.) are dominant shrubs on the grass-covered hills around the lakes. Cabbage trees (*Cordyline australis*), gorse (*Ulex europaeus*), ferns, bracken (*Pteridium* sp.), *Muehlenbeckia* spp., *Coprosma* spp. and *Fuchsia excorticata* are also present.

SHORELINE VEGETATION

Around the shores, the vegetation differs at the three lakes, although all have willow trees around part of the shoreline. At Lake Rotorua, many of the willows are dead due to a recent blocking of the outlet stream causing a further raising of the water level. Areas of flax (*Phormium tenax*) and raupo (*Typha angustifolia*) are found particularly at the outlet end, and manuka approaches close to the water. Lake Rotoiti is surrounded by weeping willows (*Salix babylonica*) and crack willows (*S. fragilis*) on the south and west shores, but flax forms the greater part of the shoreline vegetation to the north and raupo mixed with niggerheads (*Carex secta*) and *C. virgata* forms the greater part of the eastern shoreline. Raupo stands extend out into the lake. In both these lakes the shoreline is poorly defined and often formed by pedestals of *Carex* and *Juncus* spp. growing between the willows. In contrast, Leg of Mutton is surrounded almost entirely by crack willows, with only two weeping willows forming part of the shoreline vegetation. The absence of raupo and flax makes a striking contrast to the more diverse shoreline vegetation around the other two lakes. In this lake too, the shoreline is poorly defined and obscured in a tangle of willow roots and branches, making access to the lake difficult.

MORPHOMETRY

Lake Rotorua is at an altitude of 30 m above sea level, and has an area of 0.55 km^2 (Irwin, 1975). It is approximately Y-shaped, with a maximum length of 1.8 km, and maximum width 0.7 km. Inflow, as in all three lakes, is mostly by seepage and runoff, but a small stream enters, through swampland, at the head of each arm. Flax and raupo impede water flow in the outlet, which drains to the Kahutara River. The maximum depth is about 3 m, and the bottom of the lake moderately flat.

Lake Rotoiti lies at an altitude of about 40 m above sea level. It is roughly quadrilateral in shape and has an area of approximately 0.03 km^2 (2.9 ha). The bottom slopes down evenly from the shore to the deepest part at the centre of the lake, and the maximum depth is about 1.5 m, depending on the season. There are swampy inlets at the NW and SW corners of the lake, and a swampy outlet in the NE corner has been cleared to form a drainage ditch, flowing to the Kowhai River.

Leg of Mutton lake is at an altitude of about 20 m above sea level, and has an area of approximately 0.01 km^2 (1.2 ha). As the name suggests, it is shaped like a leg of mutton. There are small inlet streams to the NW and N parts of the lake. The outlet, at the SE, has been enlarged to carry overflow at times of high water levels. The maximum depth of the lake is 1 m.

The bottom of the lakes is formed by fine soft gelatinous mud, several metres in depth. The presence of this finely divided yellow-brown mud makes the water in the very shallow Leg of Mutton appear khaki in colour, and extremely turbid. The mud in the other two lakes is more greyish-brown in colour, and the water is less turbid and less coloured.

CLIMATE

With their proximity to the sea, the lakes experience a fairly mild climate. The surrounding hills shelter the two small lakes from much of the prevailing winds from the S and E. Lake Rotorua is more exposed, particularly to southerly winds. Winds from the east occur more frequently in spring and summer, whereas southerlies occur throughout the year, although there are more calm days in autumn and winter.

Air temperatures at the lakes are usually warmer than the temperatures recorded at the meteorological station on the Kaikoura peninsula, especially in cooler weather. Because of the shape of the surrounding hills, most of Lake Rotoiti loses the sun earlier in the afternoon than the other two lakes.

The annual rainfall is normally just over 1000 mm, evenly distributed throughout the year except that May usually has a slightly higher rainfall.

PHYSICAL FEATURES

WATER LEVEL

Water levels in the two smaller lakes fluctuate considerably with the season. The level is lowest at the end of the summer, February/March, and until May or June. Greatest depths are usually in July. The water level may rise very rapidly (up to a metre in a few days) after heavy rains. The level of the larger Lake Rotorua is more stable, fluctuating annually through not more than 50 cm.

TEMPERATURE

The temperature of the lake water fluctuates seasonally following changes in the air temperature. The maximum open water temperature recorded has been 27°C in January and February, with a minimum of 3°C in June and July. Because of the shallowness of the lakes, any temperature stratification between the surface and

bottom water established during the day usually breaks down at night. Maximum temperature differences recorded during the day have been 4°C in December and 3°C in January, in Lake Rotoiti.

TURBIDITY AND COLOUR

All three lakes are turbid, but Leg of Mutton is strikingly more turbid than the other two lakes, especially in winter. The turbidity and colour of the water is influenced by rainfall (particularly in Leg of Mutton) and algal blooms (particularly in Rotoiti). In Leg of Mutton the minimum Secchi Disc reading recorded is 0.09 m, in July after heavy rain, with a maximum reading of 0.52 m in April. The minimum reading in Lake Rotoiti has been 0.17 m in February and March, during an algal bloom. This period is the only time of the year when Leg of Mutton, with no algal bloom, is the clearer of the two lakes, with a Secchi Disc reading of 0.27 m. Lake Rotoiti becomes clearer with the disappearance of the algae and the Secchi Disc is visible to the bottom of the lake, at a depth of 1.07 m, during May and June. Turbidity in Lake Rotorua is more variable between different years. The lake is usually most turbid in September, when the Secchi Disc reading may be as low as 0.38 m. The time of maximum Secchi Disc reading has varied in different years between April (1.85 m), July (1.45 m) and January (1.36 m), depending on the timing of heavy rains and algal blooms.

The colour of the lake water is usually a rich khaki-brown in Leg of Mutton, but becomes greenish in Rotoiti and Rotorua at times of algal abundance.

CHEMICAL FEATURES

pH AND ALKALINITY

The pH of the open water is usually close to neutral or slightly alkaline, except at times of algal blooms. The pH of Leg of Mutton has varied between 6.7 and 7.9 (in March). In Lake Rotoiti, the pH increased during an algal bloom to 8.6 in January, and 9.3 in February. Lake Rotorua is the most acidic, with a recorded pH range of 6.4 to 7.3 (in February).

The alkalinity varies seasonally, especially in the smallest lake, Leg of Mutton. Variation is probably, in this lake in particular, mostly in relation to changes in water volume. In Leg of Mutton, bicarbonate alkalinity can vary between 0.45 and 0.92 meq. $HCO_3.\ell^{-1}$, whereas in the larger Lake Rotorua the range is usually between 0.45 and 0.63 meq. $HCO_3.\ell^{-1}$.

DISSOLVED OXYGEN CONTENT

The dissolved oxygen content of the water is least in Leg of Mutton lake, probably due to metabolic activity of bacteria living on the abundant silt particles or the decomposing willow leaves in the water. The lowest values have been found in December, when oxygen saturation may decrease to 18%. Throughout most of the year, the water in the lakes is well mixed and the oxygen content of the surface and bottom water is similar. With increasing air temperatures during summer, and the tendency for a temporary daytime stratification to develop, there is often a related difference in the oxygen content of the surface and bottom water, especially in Lakes Rotorua and Rotoiti. Whereas the oxygen saturation of the surface water remains high, that of the bottom water may decrease to 50% saturation particularly in March or early April.

IONIC CONTENT

The total ionic content of the water is high in relation to most other South Island lakes, 0.4 - 3.0 meq. ℓ^{-1} (Stout, 1975). Due to the close proximity of the lakes to the sea, and the influence of onshore winds, the lake water contains particularly large amounts of chloride and sodium. Chloride content is related to distance from the sea; it is highest in Leg of Mutton (up to 63 $g.m^{-3}$), up to 47 $g.m^{-3}$ in Lake Rotoiti, and least in Lake Rotorua (up to 16 $g.m^{-3}$). Highest values are recorded in summer when water levels are low. The sodium content of the water varies between 5 and 20 $g.m^{-3}$.

Of the nutrient ions, the amounts of nitrogen and phosphorus recorded vary greatly seasonally, but nitrogen compounds in particular may reach high values, especially in Lakes Rotoiti and Rotorua. Ammoniacal nitrogen has been recorded up to 1.57 $g.m^{-3}$, nitrate up to 2.0 $g.m^{-3}$ (in Lake Rotoiti) and total organic nitrogen up to 2.8 $g.m^{-3}$ (during January to March). Phosphorus values are usually highest in Lake Rotorua, with total phosphorus up to 0.3 $g.m^{-3}$ (in March) and soluble phosphorus up to 0.04 $g.m^{-3}$. Phosphorus enters the lakes partly from topdressing activities in the catchment, especially Lake Rotorua. Whereas all three lakes also receive some nutrients from waterbirds on and around the water, Lake Rotorua in particular receives guano from the shags which roost on the dead willow trees at the lake edge. The silica content of the water also varies seasonally and is usually most abundant (up to 10 $g.m^{-3}$) in March/April and September.

BIOLOGICAL FEATURES

AQUATIC MACROPHYTES

The presence of raupo (*Typha angustifolia*) on the shores of Lakes Rotorua and Rotoiti has been noted previously. Patches of raupo also extend out into the lake in Rotoiti, and the extent of the lake bed covered by raupo has increased in recent years.

Leg of Mutton lake has beds of *Potamogeton ochreatus*, particularly in summer and at the southeast corner of the lake. Patches of *Callitriche verna* and *Myriophyllum* spp. may be found around all three lakes, but in general macrophytes are not well developed in these lakes, probably because their turbidi reduces light penetration.

PHYTOPLANKTON

Blue-green algae are found in all three lakes, and may form conspicuous blooms. *Anabaena spiroides* usually blooms in Lake Rotoiti in January and in Lake Rotorua during March - April. In Lake Rotoiti it is often followed by a bloom of *Anacystis cyanea* (from January until March), which has also been found in Leg of Mutton. In both Rotorua and Rotoiti, the blue-green algal blooms are frequently preceded by a bloom of the filamentous diatom *Melosira granulata* var. *angustissima*.

A variety of green algae occur in Lakes Rotorua and Rotoiti. Flint (1975) records 29 species from Rotorua and 18 species from Rotoiti of which *Closterium aciculare, Micractinium pusillum, Staurastrum* spp. and *Staurodesmus* spp. may be dominant at times in Rotorua. Diatoms are slightly more diverse in Lake Rotoiti (7 species) than in Rotorua (5 species) but two species, especially *Synedra rumpens*, may be abundant in the latter lake. Chrysophyceae are more common in Rotorua, in which *Cryptomonas* and *Trachelomonas* are also dominant at times (Flint, 1975). *Trachelomonas* and other Euglenoid algae are found in all three lakes, but particularly in Leg of Mutton where they are found throughout the year, usually represented by several species. In summer (mainly January), green algae may also be common in this lake, especially *Ankistrodesmus* spp. and *Chlorella* spp.

Phytoplankton biomass, as measured by the chlorophyll content, is large during algal blooms. In the surface water, values up to 390 $mg.m^{-3}$ for Lake Rotoiti, 260 $mg.m^{-3}$ for Rotorua and 160 $mg.m^{-3}$ for Leg of Mutton have been recorded in January, and for Rotorua also in April. For phytoplankton productivity, determined by the oxygen light and dark bottle method, a maximum value for gross photosynthesis in Lake Rotorua of 340 $mgC.m^{-3}.hr^{-1}$ has been recorded in February, again a very high value.

BACTERIA

Bacterial counts from the lake water vary greatly with season and from different depths, particularly in Leg of Mutton lake. Numbers may be very high close to the bottom or after heavy rains, especially if silt has been washed into the lake or the bottom mud stirred up. The highest counts have been recorded from Leg of Mutton and the lowest from Rotorua. In all three lakes, bacterial counts appear to be high compared with other South Island lakes investigated.

MACROPHYTE AND BENTHIC FAUNA

A variety of invertebrate species occur on or among the aquatic macrophytes and in the sheltered regions close to the shore (Table 1). Molluscs are poorly represented. A few *Potamopyrgus antipodarum*, *Gyraulus corinna* and *Pisidium hodgkini* have been found, and the small freshwater limpet *Ferrissia neozelanica* is present in Leg of Mutton in larger numbers. Arthropods are particularly well represented, especially crustaceans and insects. The waterboatmen (*Sigara* spp.) and backswimmers (*Anisops* spp.) are abundant in more open water, especially from February until April. The pond skater *Microvelia macgregori* is found on more protected waters. The principal caddisfly larvae are Leptocerids (such as *Triplectides* sp.) and Hydroptilids (*Paroxyethira* spp.). Adult Zygoptera and Anisoptera are conspicuous around the edges of the lakes from November until March. The planktic cladocerans are sometimes found close to the shore, and *Simocephalus vetulus* is also present in this region, especially in Leg of Mutton and particularly during December and January. The cyclopoid copepod *Cyclops robustus* is most abundant in October, in Leg of Mutton. Several species of ostracods occur, including *Candonocypris candonoides* *Cypridopsis vidua* and *Gomphocythere duffi*. The water mites *Hydrachna maramauensis*, *Piona uncata exigua* and *Eylais waikawae* are seen especially from December until April.

Both species of freshwater hydroids have been recorded from the lakes; *Chlorohydra viridissima* is most conspicuous in Leg of Mutton, especially during April and May, and *Pelmatohydra oligactis* is more common in Lakes Rotoiti and Rotorua.

The time of greatest abundance may be different for the same species in different lakes.

Chironomid larvae and tubificid worms occur both among the macrophytes, especially in the substrate, and in the mud in the middle of the lake. Tubificids are especially numerous in Leg of Mutton. The most common chironomid is the bright red *Chironomus zealandicus*, but a species of *Anatopynia* is also present.

TABLE 1. MACROPHYTE AND BENTHIC FAUNA

Coelenterata:
Chlorohydra viridissima
\+ *Pelmatohydra oligactis*

Turbellaria:
Rhabdocoela:
Phaenocora sp.
Tricladida:
Cura pinguis

Oligochaeta:
Chaetogaster
Tubificidae

Hirudinea:
\+ *Glossiphonia multistriata*

Nematoda:

Crustacea:
Cladocera:
Alona guttata
Bosmina meridionalis
Ceriodaphnia dubia
Chydorus sphaericus
Daphnia thomsoni
Ilyocryptus sordidus
Macrothricidae
* *Simocephalus vetulus*
Ostracoda:
Candonocypris candonoides
Cypridopsis vidua
Gomphocythere duffi
Copepoda:
Boeckella hamata
Cyclops robustus
Harpacticoida

Insecta:
Odonata:

Anisoptera:
Procordulia grayi
Zygoptera:
Austrolestes colensonis
Xanthocnemis zealandica
Trichoptera:
\+ *Paroxyethira* sp.
Triplectides sp.

Hemiptera:
Anisops assimilis
Anisops wakefieldi
* *Diaprepocoris zealandiae*
\+ *Microvelia macgregori*
Sigara arguta
Coleoptera:
Liodessus sp.
Rhantus pulverosus
Diptera:
Chironomidae
Chironomus zealandicus
Culex pervigilans
* Forcipomyidae

Acarina:
Eylais waikawae
Hydrachna maramauensis
Piona uncata exigua

Gastropoda:
Ferrissia neozelanica
Gyraulus corinna
Potamopyrgus antipodarum

Bivalvia:
Pisidium hodgkini

Chordata:
Anguilla sp.
Gobiomorphus sp.

\+ Not recorded in Leg of Mutton
* Only recorded in Leg of Mutton

The fish fauna has not been investigated. Bullies (*Gobiomorphus* spp.) may be conspicuous at the edges of the lakes from November until February, and large eels are present, but other fish have not been observed.

ZOOPLANKTON

The calanoid copepod *Boeckella hamata* is the most conspicuous species in the zooplankton in all three lakes, and found throughout the year. It is usually most abundant during summer and autumn, from January until about May, or sometimes in November/December in Leg of Mutton, but the species may also be found in large numbers at other times of the year, such as June or September. The occurrence of a dinoflagellate, resembling *Syndinium*, parasitising *B. hamata* in these lakes has been reported by Burns (1965). The

parasite is particularly common when *Boeckella* populations are most numerous. Burns found that up to 26% of the population was infected at times but the effects of the parasite on the copepod are not known.

Of the three planktic cladoceran species in the lakes, *Daphnia thomsoni* and *Ceriodaphnia dubia* are common in Lake Rotoiti and present in smaller numbers in Leg of Mutton, whereas *Bosmina meridionalis* occurs in all three lakes but is most abundant in Lake Rotorua. *C. dubia* is especially common during March to June in Lake Rotoiti. *D. thomsoni*, the largest species, is most numerous in Rotoiti in June, but may also be present in April/May or November/December. In Lake Rotorua, *B. meridionalis* is present in largest numbers during March until June. The bottom-dwelling *Ilyocryptus sordidus* is sometimes found in the open water, particularly of Leg of Mutton.

The water mite *Piona uncata exigua* is found in the plankton, especially from March until May, probably feeding on the cladocerans which are most abundant at that time.

There are also a number of species of rotifers in the plankton of all three lakes. *Asplanchna* spp. are noticeable in Rotorua and Rotoiti in January and February. But a variety of other species are found at different times of the year, particularly in Leg of Mutton, where *Keratella cochlearis* and *Brachionus* sp. may be common, the latter species often during the winter months.

BIRDS

The lakes and surrounding vegetation support a large number of birds. Species which have been recorded are listed in Table 2. Fantails are especially abundant and conspicuous around the lakes.

Waterbirds are most numerous on Lake Rotoiti, where flocks of paradise shelducks, grey ducks and grey and black teal (scaup), in particular, are seen regularly on the lake. Leg of Mutton supports fewer individual waterfowl and some species, such as pukekoes, have not been seen here, presumably because the willows are not a suitable habitat. Duck shooters visit lakes Leg of Mutton and Rotorua, but not usually Rotoiti, especially during May.

Pied, white-throated and black shags roost at night on the dead willow trees around Lake Rotorua. Pied shags are the most numerous; Stonehouse (1967) estimated a summer population of 180-200 birds, decreasing to 120-130 by July. Between 40 and 60 white-throated shags roost at the lake in summer, declining to

TABLE 2. BIRDS RECORDED ON OR AROUND THE LAKES

Crested grebe (*Podiceps cristatus australis*)
White-throated or little shag (*Phalacrocorax melanoleucos brevirostris*)
Pied shag (*Phalacrocorax varius varius*)
Black shag (*Phalacrocorax carbo novaehollandiae*)
White-faced heron (*Ardea novaehollandiae*)
White heron (*Egretta alba modesta*)
Australasian bittern (*Botaurus stellaris poiciloptilus*)
Black swan (*Cygnus atratus*)
Canada goose (*Branta canadensis*)
Paradise shelduck (*Tadorna variegata*)
Mallard (*Anas platyrhynchos platyrhynchos*)
Grey duck (*Anas superciliosa superciliosa*)
Grey teal (*Anas gibberifrons gracilis*)
New Zealand shoveler (*Anas rhyncotis variegata*)
New Zealand scaup (*Athya novaeseelandiae*)
Australasian harrier (*Circus approximans gouldi*)
California quail (*Lophortyx californica brunnescens*)
Marsh creke (*Porzana pusilla affinis*)
Pukeko (*Porphyrio porphyrio melanotus*)
Southern black-backed gull (*Larus dominicanus*)
Red-billed gull (*Larus novaehollandiae scopulinus*)
Black-billed gull (*Larus bulleri*)
Caspian tern (*Hydroprogne caspia*)
Black-fronted tern (*Sterna albostriata*)
Morepork (*Ninox novaeseelandiae novaeseelandiae*)
New Zealand kingfisher (*Halcyon sancta vagans*)
South Island rifleman (*Acanthisitta chloris chloris*)
Skylark (*Alauda arvensis arvensis*)
New Zealand pipit (*Anthus novaeseelandiae novaeseelandiae*)
Hedge sparrow (*Prunella modularis occidentalis*)
Brown creeper (*Finschia novaeseelandiae*)
Grey warbler (*Gerygone igata*)
South Island fantail (*Rhipidura fuliginosa fuliginosa*) - pied and melanic forms
Yellow-breasted tit (*Petroica macrocephala macrocephala*)
Song thrush (*Turdus philomelos clarkei*)
Blackbird (*Turdus merula merula*)
Silvereye (*Zosterops lateralis lateralis*)
Bellbird (*Anthornis melanura melanura*)
Tui (*Prosthemadera novaeseelandiae novaeseelandiae*)
Yellowhammer (*Emberiza citrinella caliginosa*)
Chaffinch (*Fringilla coelebs gengleri*)
Greenfinch (*Carduelis chloris chloris*)
Goldfinch (*Carduelis carduelis brittanica*)
Redpoll (*Carduelis flammea cabaret*)
House sparrow (*Passer domesticus domesticus*)
Starling (*Sturnus vulgaris vulgaris*)
White-backed magpie (*Gymnorhina tibicen hypoleuca*)

25-30 in winter; whereas about 10-20 black shags are present throughout the year. The shags nest in colonies around the lake, breeding during July to September. Most shags feed in the sea around the Kaikoura peninsula, except the black shags which feed mostly in inland waters. Their defaecation while roosting around the lake contributes significant amounts of nitrogen and phosphorus to the water, raising the nutrient levels in Lake Rotorua.

CONCLUSIONS

Rotorua, Rotoiti and Leg of Mutton are all small, shallow lakes, very turbid for at least part of the year. Lake Rotoiti, in particular, is in an advanced stage of senescence with patches of emergent macrophytes (raupo) present even in the centre of the lake.

Lake Rotorua, the largest, is of particular interest for the colonies of shags roosting on the willow trees killed by recent raising of the water level. Shag faeces contribute nutrients to the lake, which is thus guanotrophic. Lake Rotoiti, surrounded by raupo and flax, is of particular importance as a habitat for waterbirds. The smallest, Leg of Mutton lake, is very shallow and turbid, and surrounded by willows whose leaves make an important contribution to the organic matter in the lake.

All three lakes are eutrophic, with blooms of blue-green algae, green algae or diatoms at times. In Rotorua and Rotoiti blue-green algae may form conspicuous scums on the surface of the water. Nutrients are contributed to the lakes by the birds and by farming activities in the catchments.

These lakes are of particular interest because of their birds, which attract both bird-watchers and duck-shooters.

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